

## Effects of Repeat Annual Applications of Dichlobenil on Weed Populations and Yield Components of Cranberry<sup>1</sup>

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**Abstract:** To address grower concerns that repeated use of dichlobenil could negatively affect cranberry productivity, field studies were conducted at two commercial farms in either high weed density (HW) or low weed density (LW) areas. Data from 4 yr of repeat annual applications of 0, 1.8, and 4.5 kg ai/ha dichlobenil indicated minimal negative impact on cranberry vines. Herbicide application did not affect upright productivity, leaf biomass production, percent fruit set, or other yield parameters adversely; in addition, no improvement in these parameters was noted. Although the interaction of herbicide application with weed density on cranberry root length varied with sampling date, no consistent trend (adverse or positive) was seen. The presence of weeds, rather than herbicide application, was the important determinant of yield. Vines in LW areas produced more marketable fruit and had higher percentage of fruit set than vines growing in HW areas. Repeat annual applications of dichlobenil on commercial cranberry beds may be considered as part of a viable integrated weed management program with no adverse effect on crop growth or yield.

**Nomenclature:** Dichlobenil; cranberry, *Vaccinium macrocarpon* Ait.

**Additional index words:** Herbicides, root length, vegetation survey, weed community.

**Abbreviations:** HW, high weed density; LW, low weed density.

### INTRODUCTION

Dichlobenil, a preemergence granular herbicide registered in 1964, has been used in the cranberry industry for decades to control annual and perennial grasses, sedges, and broadleaf weeds (Demoranville and Devlin 1969). Dichlobenil persistence in the soil has been documented in various agricultural ecosystems. Dichlobenil has been shown to persist in the top 15 cm of soil in cranberry beds (Miller et al. 1966) and apple [*Malus* × *sylvestris* (L.) Mill. var *domestica* Borkh.] orchards (Skroch et al. 1975). The total quantity of dichlobenil residue was higher for samples collected from cranberry beds that received two annual applications of the herbicide than for soil samples that had received a single application (Miller et al. 1966). The authors suggested that dichlobenil could persist over time and that its effect on vine health should be considered in future cranberry research.

In the reports available on the effect of long-term use of dichlobenil, results are mixed. Apple trees in North Carolina treated with five annual applications of 4.5 and 9.0 kg ai/ha dichlobenil showed no significant tree growth increases with either rate, but yield increases were noted at the high rate when compared with the untreated mowed plots (Skroch et al. 1975). Apple trees grown in eastern Ontario, Canada, treated with six annual applications of 8.8 kg/ha dichlobenil had improved tree health (e.g., greater annual increase in mean trunk and limb circumference) but no yield increase compared with untreated mowed plots (Heeney et al. 1981). Another apple study reported that six annual applications of dichlobenil at various rates (4, 8, and 16 kg/ha) were not detrimental to tree vigor or yield (Hogue and Neilsen 1988).

Massachusetts cranberry growers often have expressed concern that annual repeat applications of dichlobenil (at use rates of up to 4.5 kg/ha) caused direct vine injury or increased the susceptibility of the vines to environmental or pest stresses. The few available studies on dichlobenil use in cranberry present conflicting results. A study conducted in the mid-1960s showed that cranberry vines receiving four annual spring applications of 3.4 kg/ha dichlobenil had the highest yield (in 3 of 4 yr) compared with both untreated plots and plots receiv-

<sup>1</sup> Received for publication May 6, 2003, and in revised form December 26, 2003. This research is a part of a dissertation submitted by the senior author in fulfilling doctoral degree requirements at the University of Massachusetts–Amherst.

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ing 4.5 kg/ha of the herbicide (Demoranville and Devlin 1969). They also evaluated root health by planting cuttings taken from the treated plots (3.4 and 4.5 kg/ha) in pots in the greenhouse. Even though treated cuttings had fewer healthy roots than untreated cuttings, all treated cuttings had enough roots to predict successful rooting and vine colonization. In contrast, a published abstract noted that cranberry cuttings treated with 3.4, 5.6, and 7.8 kg/ha dichlobenil produced no new growth in a greenhouse study (Devlin and Demoranville 1974), but no subsequent paper containing specific data for this study was identified in the literature. The use of the herbicide has been associated with producing positive fruit attributes. Dichlobenil applications (3.4- and 4.5-kg/ha rates) increased anthocyanin synthesis (Devlin and Demoranville 1968).

The long-term impact of maximum rates of dichlobenil on cranberry productivity and health remains unclear, and the impact of low rates of dichlobenil (<2.0 kg/ha), commonly used in current cranberry farming, has not been examined previously. The objective of this study was to examine the effects of 4 yr of repeat annual applications of dichlobenil at low (1.8 kg/ha) and maximum (4.5 kg/ha) rates on yield components, upright characteristics, and weed species richness and diversity in commercial cranberry farms.

## MATERIALS AND METHODS

Field studies were initiated at two commercial cranberry farms, operated by the same grower, in southeastern Massachusetts during the spring of 1998. The Carver site was a 1.7-ha planting (established in 1909) of the cultivar 'Early Black', and the Rochester site was a 3.0-ha planting (established in 1935 and renovated in 1984) of the cultivar 'Howes'. Historically, the Carver site was a fresh meadow area in a flood plain (B. A. Gilmore, personal communication). The soil profile was characterized by an organic horizon (approximately 46 cm) overlaying a sand horizon. The Rochester site was a red maple (*Acer rubrum* L. #<sup>3</sup> ACRRB) swamp. The soil profile had a shallow to deep (15 to 61 cm) horizon of decomposed organic material (muck) overlaying a hardpan and gravel. The soil pH ranged from 4.0 to 4.5.

These sites were selected because the grower opted to manage segments of each farm without the application of any preemergence herbicides. The last broadcast application of dichlobenil in the production area that con-

tained the test plots was made in 1996. Previous research has shown that through bioassay indicators, dichlobenil dissipates in approximately 2 mo (Sandler and Demoranville 1999). The only herbicides applied to the test plots were those specifically used as part of the experiment.

The research plots were established before the first herbicide application (mid-April 1998). When the plots were delineated, many weeds had not expanded fully to allow appropriate assessment of their percent cover; thus, designation of low weed density (LW) and high weed density (HW) areas was initially determined by qualitative visual assessment of both species richness and approximate percent weed cover. The designation of LW and HW areas was determined on a relative basis for each location. Vegetation surveys, conducted during the summer of each year, quantified the population parameters more accurately (Sandler 2004).

The experiment was conducted as a split plot, with weed density as the whole plot, replication nested within weed density, and herbicide treatment as the split plot, randomized as a complete block within each replication. Each plot was 1.5 by 6.1 m in size. Individual plots were spaced at least 4.6 m from each other, and complete rows were at least 9.2 m apart. One set of plots was located in an area of the farm that had HW, and one set was located in an area that had LW. In each location, herbicide treatments were arranged in a randomized complete block design (with untreated borders between plots) consisting of four replicates of three treatments. HW and LW areas were specifically selected such that these two groups of 12 plots would be as close to each other as possible.

Herbicide rates and timings used in this study were based on current management recommendations for weed control in commercial cranberry (Crompton Uniroyal Chemical 2003). Multiple applications are permitted but must not exceed 4.5 kg/ha in a 12-mo period. Efficacy of dichlobenil, especially for swamp dodder (*Cuscuta gronovii* Willd. ex R. & S. # CVCGR) control, is improved when it is applied close to the time of seedling emergence (Kusek 1991). Many weed species on Massachusetts cranberry beds emerge in April or early May, and herbicide rates between 3.4 and 4.5 kg/ha are typically applied to control a wide variety of weeds. Dodder is a serious pest in commercial cranberry production, and dichlobenil is also used for dodder management. Dichlobenil rates less than 2.2 kg/ha are known to be efficacious when applied to coincide with dodder seedling emergence (Kusek 1991), and dodder seedlings

<sup>3</sup> Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

emerge later than other target species. Thus, to represent conventional industry practices, these timings and herbicide ranges were considered when the study treatments were assigned.

For the next 4 yr, plots were treated with one spring application of dichlobenil at the rates of 1.8 kg ai/ha (low rate) or 4.5 kg ai/ha (maximum rate) or were left untreated. Maximum rates of dichlobenil were applied on April 12, 1998, April 19, 1999, April 7, 2000, and April 17, 2001, and low-rate applications were made on April 29, 1998, May 3, 1999, May 15, 2000, and May 10, 2001. The herbicide was applied as uniformly as possible using a hand-held plastic shaker with a screw lid (approximate dimensions: 85-mm height, 60-mm-diam width, and pore aperture of 2 mm, with a range of 90 to 95 pores per lid). The shaker was held approximately 30 cm above the vine canopy during the delivery of the herbicide. All applications were made when the wind speed was less than 1.8 m/s. The herbicide was watered in immediately after application using conventional cranberry irrigation systems, comprising equally spaced sprinkler heads fixed upon short risers, or hand-held sprinkler cans (Rochester site 1999 only). Approximately 38,050 L/ha water was delivered to both test areas after every application in all years of the study.

**Upright Evaluation.** Cranberry vines consist of lateral woody runners that support numerous intermittent vertical stems (uprights). In any given season, uprights can be either vegetative or fruit bearing. The proportion of flowering (fruit bearing) uprights (% $U_F$ ) in an upright population, as well as percent fruit set, are important indicators of yield (Eaton and Kyte 1978). A sampling procedure (DeMoranville and Davenport 1997) previously used in cranberry research to evaluate yield components was modified slightly for this study. One vine sample was collected twice per year from every plot by excising all uprights close to the bog surface within a 180-cm<sup>2</sup> area. Sampling templates were made by cutting 15-cm-diam polyvinylchloride pipe into 2.5-cm-wide bands. The sampling ring was placed randomly in a plot and positioned as close to the bog surface as possible. Using conventional hand clippers, cuts were made around the entire inner perimeter to permit collection of runners that were passing through the area of the ring. The uprights were then held together and clipped as close as possible to the bog surface. The samples were placed in small resealable plastic bags and transferred to the freezer for storage at -20 C until evaluations were made. Sample collection dates were June 9, 1998 (single sampling date); June 3, September 7 (Carver), and No-

vember 10 (Rochester) 1999; May 30, September 5 (Rochester), and September 8 (Carver) 2000; and June 21 and August 24, 2001.

Uprights collected in spring (the single sample collected in 1998 was included in this evaluation) were evaluated for number of flowering and nonflowering uprights (previous and current years) and leaf dry weight. Leaves comprise most of the new aboveground biomass produced by cranberry vines each year, and new leaves are important for supporting fruit set and sizing (Roper and Klueh 1994). Uprights were dried for at least 48 h at 60 C. The leaves then were removed from the woody portions of the upright, and leaf dry weight was recorded.

Total number of uprights ( $U_T$ ) was obtained by summing flowering and nonflowering uprights, and percent  $U_F$  was calculated. Initial upright density was determined by counting the number of woody uprights (old growth) collected from within the ring template. Upright density of the old growth was determined by counting the number of woody stems present per vine sample collected from the ring templates. The number of uprights (per unit area) from the old growth is representative of the density of persistent woody uprights that remained alive after winter. These older woody stems bear the new upright growth upon which fruit may be produced in any given year.

For the current year evaluation, the new growth was usually expanded enough to determine reproductive status. However, newly expanded uprights (with reproductive status unknown) and uprights with terminal buds or dead tips were also included in the count to tabulate the total number of new uprights in the spring sampling. The absolute number of new uprights may not give a correct assessment of treatment effects because the number of old uprights can vary across the bog owing to many factors other than treatment effects (C. J. DeMoranville, personal communication). To evaluate treatment effect on any inherent upright density variation that may have been present, percent change in upright density was calculated by dividing the difference between the total number of new and old uprights by the original number of old uprights and multiplying by 100.

Uprights were evaluated in the latter part of the season to determine percent  $U_F$ ,  $U_T$ , percent fruit set, number of new terminal buds, and leaf dry weight. Fall samples were collected from 1999 through 2001; only one sampling date occurred in 1998, and these data were grouped with the spring samples. For the fall sampling (years other than 1998), percent  $U_F$  was determined based on



the status of the current year's growth. Because terminal buds in cranberry are formed in late summer and are considered to be good indicators of yield potential (Lacroix 1926), the number of uprights with new terminal buds was also determined. The numbers of pedicels (indicative of unfertilized flowers) and fruit were determined for uprights collected within each ring template to calculate percent fruit set. Leaf dry weight was determined as described above for the spring upright samples.

**Cranberry Root Length Estimates.** Root lengths were measured using a 30-mm-diam metal soil-sampling tube that had a length of 31 cm. The tube had an open portion of the cylinder at the lower end that permitted direct measurement of the roots upon extraction of the soil core. Root lengths were measured three times during the course of the study: June 14, September 5 (Rochester) and September 11 (Carver), 2000, and August 2, 2001. Four 15-cm-deep soil cores were taken from each plot, and root lengths were measured and averaged to generate a value for the plot. Root length was measured with the soil core in place in the sampling tube (B. D. Lampinen, personal communication). Root length (a field estimate of rooting depth of new and existing roots) was determined to be the distance from the soil surface to the end of root extension.

**Yield.** Plots were harvested in September each year. A 930-cm<sup>2</sup> area was selected randomly for each replicate, and all berries within this area were collected. Fruit were stored and evaluated according to previously published protocols (Sandler 1995). The fruit were stored at 5 C in paper bags and visually evaluated for field rot within 1 wk. To approximate the size of berries collected during commercial harvesting, very small fruit were removed before evaluation. The samples were passed over a 5.6-mm sieve<sup>4</sup> to eliminate nonpollinated, undersized, and aborted fruit. Fruit were categorized as healthy, rotted, or damaged. The number of fruit and the corresponding biomass of each fruit category were determined. All fruit were placed back in cold storage at 5 C and reevaluated for storage rot 8 wk after harvest.

Fruit infected by fruit rot fungi, exhibiting signs of physiological damage, damaged by insects or weather, or bruised by mechanical means were deemed unusable. Useable or marketable yield was determined by taking the weight of all healthy berries collected from the sample area. Percentage of unusable yield was determined

by dividing the sum of berries that were rotted or damaged by the total number of berries collected and multiplying by 100.

**Vegetation Surveys.** Using a square-meter quadrat, surveys of the vegetation in the treated and nontreated areas were conducted on an annual basis. The survey dates for this study were June 19 (Carver) and July 1 (Rochester), 1998, August 10, 1999, August 18, 2000, and August 6, 2001. Presence of each plant species was estimated visually using percent estimate of coverage by the plant species. Ten estimate groupings were used (see below). Two observers recorded their estimations independently. Resolution of discrepancies, spaced by more than one group, was the average between the groups. Resolution of discrepancies for adjacent groups was obtained by re-evaluation. Most species were identified in the field or through the use of common flora (Gleason and Cronquist 1991; Uva et al. 1997). Unknown species were sent to the UMass Herbarium for identification. Complete data on detailed plant community composition are presented elsewhere (Sandler 2004).

To facilitate data analysis with PC-ORD,<sup>5</sup> percent cover ranges were assigned integer values: 0% = 0, <1% = 1, 1 to 5% = 2, 6 to 10% = 3, 11 to 25% = 4, 26 to 40% = 5, 41 to 60% = 6, 61 to 75 % = 7, 76 to 90% = 8, >90% = 9. Data were analyzed with PC-ORD to obtain species richness (number of species present) and the Shannon diversity index (Shannon and Weaver 1949). To estimate percent ground cover based on integer values, the midpoint of each cover class range (percentage), *y*, was plotted against the cover class (integer) value, *x*. The best-fit relationship was the third-order polynomial equation

$$y = -0.165x^3 + 3.28x^2 - 5.42x \quad (R^2 = 0.99) \quad [1]$$

Mean integer values for each treatment evaluation were inserted in the equation, and percent cover was calculated.

**Statistics.** *F* tests (via Proc Mixed and Slice option) were used to test for main effects and their interactions for all data.<sup>6</sup> ANOVA model assumptions were tested through residual analyses (Bowley 1995). For spring upright samples, percent *U<sub>F</sub>* was transformed using arcsine square root; *U<sub>T</sub>* and leaf dry weight data were log-transformed. For fall upright samples, leaf dry weight data

<sup>4</sup> U.S.A. Standard Testing Sieve, No. 3.5, Fisher Scientific Co, 600 Business Center Drive, Pittsburgh, PA 15205.

<sup>5</sup> PC-ORD Multivariate Statistics Software, Version 4.2, MJM Software, P.O. Box 129, Gleneden Beach, OR 97388.

<sup>6</sup> SAS Proc Mixed Procedure and Slice Option, Release 8.2 2 (TS2M0) of the SAS System for Microsoft Windows, SAS Institute Inc., SAS Campus Drive, Cary, NC 27513-2414.

were log-transformed, and the numbers of terminal buds were transformed using arcsine square root. Yield data were also transformed using arcsine square root. Analyses were performed on the transformed data and the means of the transformed data. Means were back-transformed to their original units for manuscript presentation.

If site by treatment interactions were not significant ( $P > 0.05$ ), data from Carver and Rochester were pooled for further analysis. Similarly, if year by treatment interactions were not significant ( $P > 0.05$ ), year data were pooled. Orthogonal polynomial contrasts were used to describe the best-fit relationships for significant continuous main effects and their interactions. Significant effect of weed density was evaluated by  $F$  tests generated with the Slice option in SAS Proc Mixed.<sup>6</sup>

Vegetation survey data were first analyzed using a multivariate software package, PC-ORD. This software was used to generate basic descriptive statistics and diversity measures including mean and total species values, species richness, and Shannon diversity index. Data conformed to ANOVA model assumptions. Parameters were analyzed in SAS, using Proc Mixed to determine treatment effects.

## RESULTS AND DISCUSSION

**Spring Upright Evaluation.** ANOVA indicated that neither weed density nor herbicide application affected the total number of uprights in the old growth in any given year or at the end of the 4-yr period (Sandler 2004). The treatments did not affect the original stand density of the cranberry planting adversely or positively; the number of woody uprights per unit area remained consistent throughout the study.

In 2 of the 4 yr (1998 and 2001), vines in the LW areas have a higher percent  $U_F$  (Table 1) than vines in the HW area. This is likely due to the alternate bearing habit of cranberry (Roper et al. 1993; Strik et al. 1991) or environmental factors, rather than annual changes in the weed density. Herbicide rate had no effect on percent  $U_F$  (data not shown).

Site and treatment interacted to affect total number of uprights ( $U_T$ ) of the new growth, so data were analyzed by site. Weed density and herbicide rate interacted to affect  $U_T$  at Carver. No significant differences were noted at Rochester (Sandler 2004). Annual data for the Carver site were pooled because year by treatment interactions were not significant. Partitioning the sum of squares indicated significance for the untreated plots only. Plots located in the untreated HW location had a

*Table 1.* Interaction of high weed density (HW) and low weed density (LW), and year on percentage of flowering uprights (vertical stems) collected in spring (sites pooled,  $n = 24$ ) and total number of uprights and leaf dry weight ( $n = 12$ ) in fall samples collected from two cranberry study sites treated with various rates of dichlobenil. Data are averaged across herbicide rate. Means with similar letters (within year) are not significantly different according to the respective  $P$  values.<sup>a</sup>

Weed density	1998	1999	2000	2001
Flowering uprights—spring (sites pooled)				
	%			
LW	16.8 a	16.3 a	16.5 a	29.9 a
HW	10.1 b	16.3 a	14.1 a	18.7 b
Pr > $F$	0.002	NS	NS	<0.001
Total number of uprights—fall (Rochester)				
	1,000/m <sup>2</sup>			
LW	ND	7.37 a	7.64 a	6.41 a
HW	ND	6.32 a	5.97 b	6.58 a
Pr > $F$		NS	0.009	NS
Leaf dry biomass—fall (Carver)				
	kg/m <sup>2</sup>			
LW	ND	0.54 a	0.58 a	0.55 b
HW	ND	0.63 a	0.57 a	0.78 a
Pr > $F$		NS	NS	<0.001

<sup>a</sup> Abbreviations: NS, nonsignificant at the 0.05 level; ND, no data collected.

higher  $U_T$  (16,300 uprights/m<sup>2</sup>) than those in the LW section (14,600 uprights/m<sup>2</sup>). Because percent  $U_F$  was higher in the LW plots, the increase in  $U_T$  in the HW plots may be ascribed to an increased production of vegetative uprights. HW and LW plots treated with low-rate and maximum-rate applications of dichlobenil had the same  $U_T$ . This response would indicate that the vines treated with either rate of the herbicide could produce equivalent numbers of new uprights whether growing among weeds or not.

Weed density affected the percent change in upright density; herbicide rate had no effect (data not shown). Year by treatment and site by treatment interactions were pooled. The percent change in upright density was higher in plots located in the HW area (76.3%) than for vines collected from the LW area (61.3%). Upright density and composition may vary for several reasons. An individual cranberry upright typically produces one bud (which develops into an upright) but may produce several buds in some years, thus increasing the density of new uprights. In addition, cranberry vines are alternate bearing (Roper et al. 1993; Strik et al. 1991) and produce a mixed composition of flowering and vegetative uprights in any given year. As with  $U_T$ , the increase in upright density in the HW plots may be ascribed to an increased production of vegetative uprights (LW plots had a higher percent  $U_F$ ).

Mean leaf dry weight for the spring samples was not

affected by weed density or herbicide rate (data not shown). It is not clear why weed density and herbicide application had minimal effect on cranberry leaf weight for the spring samples. Different weed species are known to have variable impact on cranberry growth and yield (Else et al. 1995); however, the relationship of weed density (for the wide range of weed species present in cranberry farms) with cranberry biomass is not well known. The 4-yr average indicated very little difference in spring mean leaf weight for vines treated with various herbicide rates and growing in LW and HW areas (range of 0.50 to 0.58 kg/m<sup>2</sup> for the six treatment combinations); however, data were quite variable. Leaves are known to be important constituents affecting yield and overall plant health (Roper and Klueh 1994). Even though one might expect an improvement in plant biomass with the use of herbicides, data indicated that repeat herbicide applications did not have a deleterious effect on leaf biomass for vines collected in spring.

**Fall Upright Evaluation.** ANOVA indicated no significant effects of weed density or herbicide rate on percent  $U_F$  for vines collected in the fall (Sandler 2004). In contrast, spring-collected vines from LW areas had higher percent  $U_F$  than vines collected from HW areas in 2 of the 4 yr (Table 1). Even though initial percent  $U_F$  may be higher in some years, other factors, such as fertilizer application or cultural practices, may play a more important role in end-of-season percent  $U_F$  production than weed density (Eck 1976; Strik and Poole 1991).

The effect of weed density on  $U_T$  varied at each site. The effect of weed density on  $U_T$  varied by year at Rochester. Herbicide treatment had no effect on  $U_T$  at either site (data not shown). In 2000 only,  $U_T$  was greater in the LW portions of the bog at Rochester than in the HW areas in the plots (Table 1). LW areas had slightly higher  $U_T$  ( $P = 0.046$ ) at Rochester, and the response in 1 yr at one site is likely due to chance. No treatment effects were seen at Carver. Overall, weed density had minimal effect on  $U_T$  for both spring and fall samples.

The effect of weed density on leaf dry weight also varied by site. The effect of weed density varied with year at Carver; no treatment effects were seen at Rochester (Sandler 2004). Leaf dry weight was increased slightly in HW areas. In 2001 only, leaf dry weight was higher in the HW plots than in the LW plots (Table 1). The increase in dry weight may be due to the trend toward higher  $U_T$  in the HW locations at Carver. Vines in the HW areas may be putting more resources into vegetative growth (lower percent  $U_F$  seen in HW areas). No-

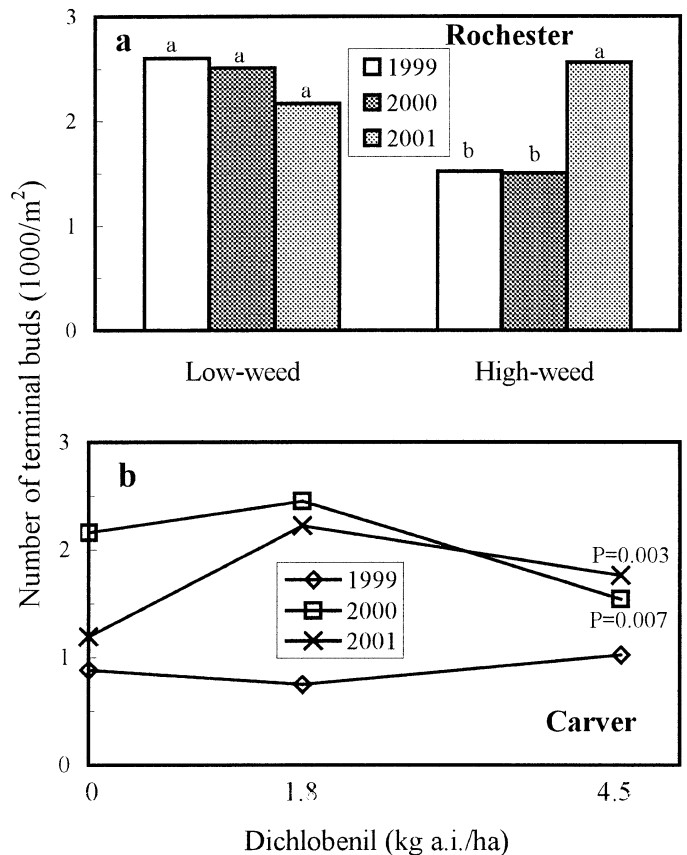


Figure 1. Interaction of (a) weed density and year at Rochester (averaged across herbicide rates,  $n = 12$ ) and (b) herbicide and year (2000 and 2001 only) at Carver on number of terminal buds (averaged across weed density,  $n = 8$ ) collected in the fall from cranberry vines treated with various rates of dichlobenil. Means with similar letters within year are not significantly different ( $P < 0.010$ ).

tably, herbicide application did not affect leaf biomass production (data not shown).

Weed density affected the percentage of fruit set at Carver. No treatment effects were noted at Rochester. Averaged over the 4 yr, percent fruit set was higher in plots located in the LW area (33.2%) than in those in the HW area (25.7%). Notably, herbicide rate had no effect on percent fruit set.

Site by treatment interactions were significant for number of new terminal buds and percent fruit set, and data were analyzed by site. The terminal bud is considered to be a mixed bud, containing floral initials and a vegetative meristem (Eck 1990). Weed density was the influential treatment at Rochester, and herbicide affected the number of terminal buds at Carver. At Rochester, higher numbers of terminal buds were seen in the LW areas in 1999 and 2000 (Figure 1a). This trend was not seen in 2001 because HW and LW locations had the same number of terminal buds ( $P > 0.05$ ).

At Carver, the effect of herbicide on the number of



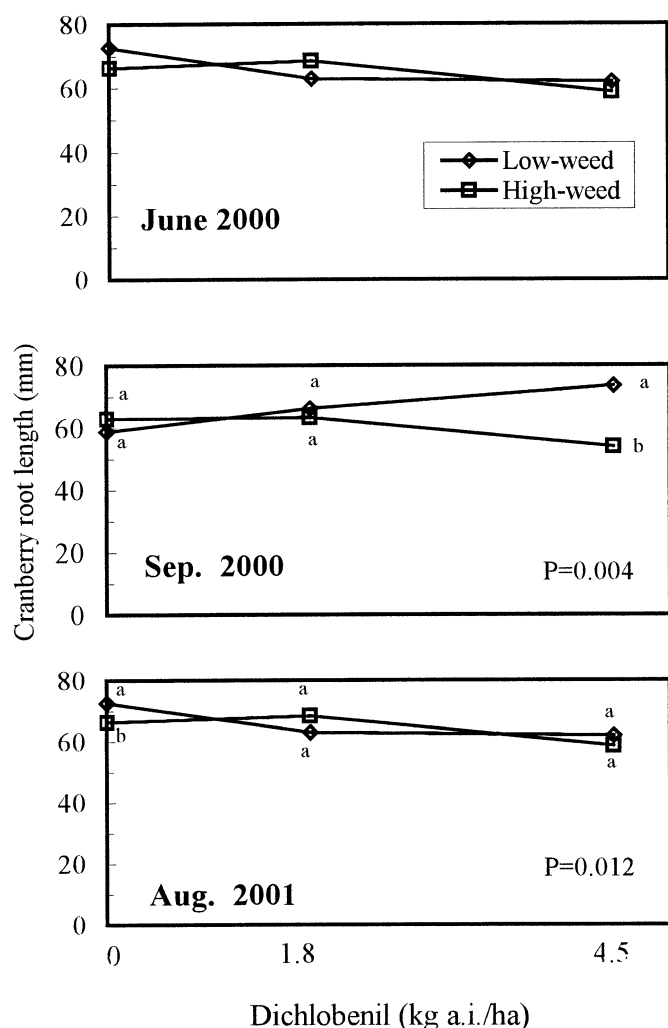


Figure 2. Interaction of weed density and herbicide rate with date of sampling on cranberry root length (averaged across sites,  $n = 8$ ). For each herbicide rate, means with similar letters are not significantly different according to the respective P value.

terminal buds varied by year. Significant effects were noted in 2000 and 2001; however, the effect of herbicide cannot be described consistently (Figure 1b). Averaging across herbicide rate, plots receiving the low-rate herbicide treatment had the highest number of buds in both 2000 and 2001 (2,450 and 2,220 buds/m<sup>2</sup>, respectively) compared with the untreated and the maximum-rate application. The effect of herbicide on number of buds is not consistent for these 2 yr. In 2000, the untreated plots had the next highest number of buds (2,160 buds/m<sup>2</sup>); in 2001, the maximum-rate herbicide plots had the next highest number of buds (1,760 buds/m<sup>2</sup>).

**Cranberry Root Length.** Weed density and herbicide rate interacted to affect cranberry root length, and this effect varied by date of sampling (Figure 2). Results were mixed. No treatment effects were seen for the first

sampling date (June 2000). Cranberry root lengths were greater in the LW location than in the HW location in plots treated with the maximum rate of dichlobenil (September 2000) or left untreated (August 2001). No consistent trend in root length (adverse or positive) was seen. It is probable that more frequent sampling would help delineate treatment effects. Further work is needed to determine whether herbicide application or weed presence (or both) affects cranberry root length adversely or positively.

**Yield.** No significant treatment effects were noted for weight per healthy berry in any year (Sandler 2004). Because the interaction of year and treatment on marketable yield was not significant, year data were pooled. Marketable yield is the weight of healthy fruit that can be sold to a handler. More marketable yield was produced in the LW locations (18.8 Mg/ha) than in vines in the HW area (13.2 Mg/ha). Repeated annual applications of dichlobenil, whether applied at low or at maximum rates, did not affect yield of cranberry adversely (data not shown). Even though yield is not improved, herbicide use is still valuable because lower weed densities allow more effective implementation of other horticultural practices such as harvesting and may provide other benefits such as minimizing pest refugia. In addition, only 4 of the 22 species at Carver and 3 of the 13 species at Rochester are considered to affect yield significantly (Else et al. 1995). Yield may be improved in situations where a greater number of weed species that can be controlled by dichlobenil are present.

The effect of weed density on commercially unusable yield varied by site. A higher percentage of unusable yield was produced in the HW plots at Carver (23.2%) than in the LW plots (15.1%); no treatment effects on percent unusable yield were seen at Rochester (data not shown). This may be due to cultivar differences (Carver: Early Black and Rochester: Howes). Early Black vines tend to produce denser canopies than Howes vines and may create microenvironments that make fruit more susceptible to fruit and physiological rot (Caruso and Ramsdell 1995).

**Vegetation Surveys.** Nine and 10 weed species (a total of 16 different species) were initially detected at Rochester and Carver, respectively, during the 1998 summer survey (Table 2). Initial densities ranged from <1% for common groundnut (*Apios americana* Medikus) and coastal plain flat-topped goldenrod [*Euthamia tenuifolia* (Pursh) Nutt.] to 8% for three-nerved joe-pye weed (*Eupatorium dubium* Willd.) at Carver. Initial densities

Table 2. Mean initial and final percent cover ( $n = 12$ ) and dichlobenil susceptibility of weed species detected at the inception of the research project for the Carver and Rochester locations from high weed density (HW) and low weed density (LW) plots of cranberry vines treated with various rates of dichlobenil.

Species common names <sup>a</sup>	Weed cover								Dichlobenil susceptibility
	Carver				Rochester				
	LW		HW		LW		HW		
	1998	2001	1998	2001	1998	2001	1998	2001	
	%								
Bristly dewberry	ND <sup>b</sup>	ND	5	6	ND	7	3	2	No
Common blackberry	ND	ND	7	6	ND	ND	ND	ND	No
Common groundnut	ND	ND	1	25	ND	ND	ND	ND	No
Fall panicum	ND	ND	1	7	ND	ND	7	6	Yes
Fireweed	ND	ND	ND	ND	ND	ND	ND	9	Yes
Flat-topped goldenrod	4	6	1	4	4	13	14	38	No
Lanceleaf violet	6	3	ND	2	1	1	4	2	No
Meadowsweet	7	ND	ND	7	ND	ND	ND	ND	No
New England aster	7	ND	4	ND	ND	ND	ND	ND	Yes
Nutsedge	ND	ND	ND	ND	ND	8	7	3	Yes
Poison ivy	ND	ND	ND	ND	ND	7	7	ND	No
Red maple	7	1	7	7	6	1	7	6	No
Rice cutgrass	ND	ND	ND	5	ND	ND	4	ND	Yes
Swampcandle	ND	7	ND	6	ND	ND	8	1	Yes
Swamp dodder	ND	ND	8	ND	ND	ND	ND	ND	Yes
Three-nerved joe-pye weed	ND	7	8	ND	ND	ND	ND	ND	No

<sup>a</sup> Scientific names of plants not mentioned in text: bristly dewberry, *Rubus hispidus* L. # RUBHI; common blackberry, *Rubus allegheniensis* T. C. Porter; fall panicum, *Panicum dichotomiflorum* Michx.; fireweed, *Epilobium angustifolium* L. # CHAAN; meadowsweet, *Spiraea alba* Duroi; New England aster, *Aster novae-angliae* L. # ASTNA; nutsedge, *Cyperus dentatus* Torr.; poison ivy, *Toxicodendron radicans* (L.) Ktze. # TOXRA; rice cutgrass *Leersia oryzoides* (L.) Sw. # LEROR; swampcandle, *Lysimachia terrestris* (L.) B.S.P. # LYTE.

<sup>b</sup> Abbreviation: ND, not detected.

ranged from <1% for lanceleaf violet (*Viola lanceolata* L. # VIOLA) to 14% for coastal plain flat-topped goldenrod at Rochester. During the course of the study, 13 and 22 weed species (a total of 24 different weed species) were identified at Rochester and Carver, respectively.

Few studies are available that document percent weed coverage values for *Vaccinium* crops. Recent research reported total mean weed cover from a survey of low-bush blueberry (*Vaccinium angustifolium* Ait.) fields in Quebec to be approximately 15% (Lapointe and Rochefort 2001). This work also indicated that weed coverage of 8% or greater depressed blueberry yield. Percent weed

cover values from this Canadian study were slightly lower than data from another low-bush blueberry study indicating that weed coverage ranged from 11 to 19% (Yarborough and Bhowmik 1989). Although the specific plant community composition may vary between research sites, the percent weed cover data obtained during this study were comparable with those of previously published *Vaccinium* research reports.

In all years, LW plots had lower mean percent weed cover (% Cover) than HW plots (Table 3). Percent cover increased in the HW and LW plots from the inception of the study to the end. Notably, no effect of herbicide treatment was seen for % Cover. Of the 22 weed species identified at Carver, only eight are controlled by dichlobenil applications. Similarly, only 5 of the 13 weed species identified at Rochester are controlled by dichlobenil (Crompton Uniroyal Chemical 2003; Dana et al. 1965; Demoranville and Cross 1964).

The lack of weed control in this study by dichlobenil would seem to preclude its usefulness in cranberry production. However, many of the weed species present at the two study sites are not considered to be susceptible species for control with dichlobenil (Table 2). The primary purpose of this research was to determine whether repeated annual applications of dichlobenil were deleterious to cranberry. It is assumed that growers would use this herbicide on weed populations that would be

Table 3. Percent weed cover (sites pooled,  $n = 8$ ) in high weed density (HW) and low weed density (LW) plots of cranberry vines treated with various rates of dichlobenil. P values are for means averaged across herbicide rate.

		Weed cover			
Rate	Weed density	1998	1999	2000	2001
kg ai/ha		%			
0	HW	2.9	4.3	5.8	8.9
	LW	2.0	0.6	0.7	2.7
1.8	HW	3.8	3.2	15.0	10.5
	LW	0.9	0.5	1.1	1.8
4.5	HW	6.3	4.1	6.0	14.5
	LW	0.3	0.3	0.4	0.5
Mean	HW	4.3	3.9	8.9	11.3
	LW	1.1	0.5	0.7	1.7
Pr > F		<0.001	<0.001	<0.001	<0.001



controlled by dichlobenil. Presuming the inclusion of more susceptible weed species, the effect of weed density on dichlobenil efficacy could be an area of future research.

Within each herbicide rate, % Cover (Table 3) was increasing more slowly in the LW plots over the years than in the HW plots. To determine the effect of treatment on these trends, the percent change in % Cover from 1998 to 2001 was calculated and analyzed for treatment effects. Site data were pooled. Initial weed density significantly influenced final weed density. Averaged across herbicide rates, HW plots had an increase in weed coverage (+40%), whereas LW plots showed a minimal decrease (−1%). Herbicide application tended to decrease percent change in % Cover, but large variability within herbicide treatments precluded finding statistical differences.

Plant communities can be described by many attributes including species richness (the number of species within a unit area), evenness (the distribution of individuals among species), and species diversity indices (Barbour et al. 1987). Species diversity indices are mathematical expressions that combine species richness and evenness into a single number. Richness and diversity are often positively correlated but not always (Hurlbert 1971).

Species richness was lower in the LW plots (1.95 species/m<sup>2</sup>) than in the HW plots (2.98 species/m<sup>2</sup>). Species richness decreased slightly ( $P = 0.049$ ) as herbicide rate increased (untreated, 2.79 species/m<sup>2</sup>; 1.8 kg/ha, 2.47 species/m<sup>2</sup>; 4.5 kg/ha, 2.12 species/m<sup>2</sup>). Orthogonal polynomial contrasts indicated that the best-fit relationship with herbicide rate was linear; species richness declined as herbicide rate increased.

The effect of weed density on Shannon diversity index,  $H'$ , varied by site. Diversity was lower in the LW plots (0.29) than in the HW plots (0.87) at Carver irrespective of herbicide application. No differences were noted at Rochester (data not shown). For relative comparison with other plant communities, the values in this study indicated plant communities of minimal plant diversity (values <1). Values for Shannon diversity index vary from 0 (community of one species) to 7 or more in very rich plant communities (DeJong 1975). Species diversity was not affected by herbicide application (data not shown). Even though species richness declined slightly with herbicide rate, the overall effect of herbicide rate on the measured vegetative parameters was minimal.

Despite grower concerns about the detrimental effect

of long-term use of dichlobenil, these studies indicated minimal negative impact of repeat annual applications. Herbicide application did not affect upright productivity, biomass production, or percent fruit set adversely. Repeat annual applications of dichlobenil, whether applied at low or at maximum rates, did not affect any yield parameters. This is in accordance with previous work where applications of dichlobenil did not affect various growth parameters in apples (Heeney et al. 1981; Hogue and Neilsen 1988) and in cranberries (Devlin and Demoranville 1974).

Different weed species are known to variably affect cranberry crop productivity (Else et al. 1995). Weed communities in commercial cranberry production areas are known to vary from site to site (H. A. Sandler, unpublished data). The two research locations used in this study contained a complex of weed species unique to these particular sites. Extrapolation of data from this study must consider that other factors such as cranberry variety, management practices, site characteristics, as well as weed community composition may influence response trends for cranberry yield components.

The presence of weeds, rather than herbicide application, was the important determinant of yield performance. This finding is supported by previous research that showed that yield and yield components were reduced in weedy areas (Yas and Eaton 1982). Vines in HW areas produced less marketable yield and put more resources into producing fruit that would be considered commercially unacceptable. Further work is needed to determine whether herbicide application or weed presence (or both) affects cranberry root length adversely or positively. Results from this study suggest that repeat annual applications of dichlobenil on commercial cranberry beds may be considered as part of a viable integrated weed management program with no adverse effect on growth or yield.

## ACKNOWLEDGMENTS

We gratefully acknowledge the cooperation of Gilmore Cranberry Company of South Carver, MA, and the use of their property during the course of this study. We also thank P. Alpert, C. M. Sparich, L. C. Hendrickson, and anonymous reviewers for constructive comments on the manuscript and K. Searcy of the UMass Herbarium for identification of weed species.

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